最近の技術から

Application of Phase Only Spatial Light Modulators to Interferometry

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1. Introduction

In the past few years there has been much interest in optical modulators which use liquid crystals. Liquid crystal devices have the advantages of low power operation, ease of use, cheapness, and reliability. Their most well-known application is as intensity modulators in flat panel displays where the liquid crystal is usually arranged in a twisted nematic configuration and polarisation effects are used. Intensity modulators of this type include numerical displays, laptop computer screens, and pocket televisions.[1] More recently, twisted nematic devices have been used as input modulators in coherent optical information processing systems such as high speed optical correlators.[2]

Although they are most often used in intensity modulators, nematic liquid crystal devices are in fact optical phase modulators whose modulation characteristic is polarisation dependant. The particular properties of any given liquid crystal layer depend on the configuration of the liquid crystal molecules, and certain configurations can be used to rotate the polarisation of the light (e. g. 90 degree Twisted Nematic type commonly found in displays) or convert from linear to elliptical polarisation and vice versa (e. g. Hybrid Field Effect type with 45 degree twist found in the Hughes Liquid Crystal Light Valve).

Nematic liquid crystals can also be configured with no twist (parallel configuration) so that they modulate phase without affecting polarisation,[3] and this makes it possible to construct a two-dimensional optical phase modulator using techniques very similar to those used to manufacture liquid crystal display panels. These modulators have many potentially interesting applications-particularly in the field of precision measurement where they can be incorporated into interferometers to produce arbitrary reference wavefronts,[4] or simply used as phase-shifting optical elements whose two-dimensional characteristics allow instruments to be constructed which have great versatility.

In this paper we shall describe two shearing interferometers which use nematic liquid crystal devices as phase shifters to achieve high accuracy and convenience of operation. The first is a speckle shearing interferometer where a parallel nematic liquid crystal cell is used to introduce a phase shift between the sheared and non-sheared speckle patterns, and the second is a Murty-type shearing interferometer for determining wavefront profile, where a two-dimensional phase modulator is used as a phase shifter to obtain high accuracy quantitative measurements automatically.

2. Surface deformation measurement using a speckle shearing interferometer

Speckle shearing interferometry is a useful technique which has been developed by Professor Toyookas group[5] for measurement of the deformations of rough surfaces. Speckle shearing interferometers are simple and extremely stable instruments which are easy to operate. The phase distribution of the output interference fringes is proportional to the gradient of the deformation of the surface under test in the direction of shear. However, the potential of these instruments for high accuracy measurement has until recently not been realised because of the difficulty of applying phase shifting techniques to determine the fringe phase distribution accurately. This problem was over-

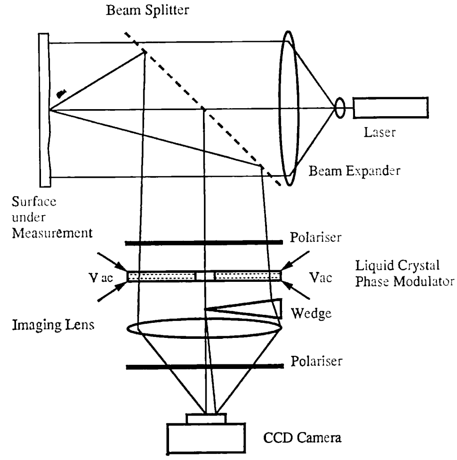

Fig. 1 Speckle shearing interferometer.

come by the application of a nematic liquid crystal phase shifter as shown in **Fig. 1.**[6] This phase shifter has only two pixels which are modulated in turn, thus applying positive and negative phase shifts to the fringe pattern. Images of these shifted patterns, together with an image of the pattern with zero shift, are used in a phase-stepping algorithm to determine the fringe pattern phase distribution in two dimensions. Integrating this numerically along the direction of shear gives the surface deformation.

The application of the liquid crystal phase modulator to this interferometer increases the accuracy and resolution of the instrument while still retaining the original advantages of simplicity and stability.

3. Wavefront shape measurement using a phase shifting shearing interferometer

Figure 2 shows the optical system of a phase-shifting shearing interferometer developed at the Mechanical Engineering Laboratory for testing collimator lenses. This is a modification of the very elegant interferometer originally described by Murty.[7] Although the Murty plate interferometer is very simple, it has until now been very difficult to apply phase shifting techniques to it and evaluation of the output fringe patterns has usually been carried out by eye or image processing techniques. Simply placing a phase-only spatial light modulator in front of the shearing plate as shown in the diagram allows phase-shifting to be applied. In this instrument, the shear is horizontal so that when a vertical phase modulating stripe is written on the LC panel, two adjacent phase shifted stripes appear in the fringe pattern at the output. The fringe phase shifts in these are of equal magnitude but opposite sign. The fringes in the output stripes may be scanned by varying the modulation depth of the phase stripe written on the panel. By writing vertical phase stripes in turn at different horizontal positions on the panel, and varying the phase modulation depth whilst detecting the intensity variation in one of the corresponding modulated stripes in the fringe pattern (always the same one, left or right), the fringe phase distribution may be determined to high accuracy (about 1/30th wavelength). Numerical integration in the horizontal direction then gives the phase distribution of the input wavefront.

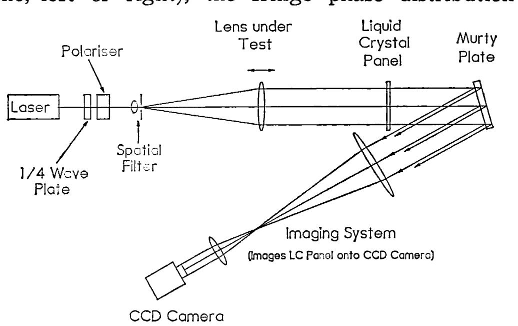

Fig. 2 Phase-shifting Murty interferometer.

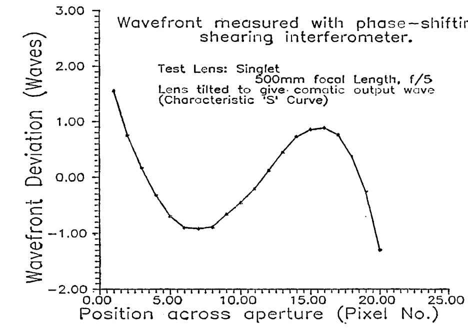

Fig. 3 Typical result from phase-shifting Murty interferometer.

This instrument has been used to measure the shapes of wavefronts produced by collimator lenses with spherical aberration and coma, with accuracies of the order of 1/20 wavelength (633 nm) and repeatabilities of better than 1/50 wavelength. A typical result is shown in **Fig. 3.** As in the speckle shearing interferometer, this instrument retains the simplicity and stability which are characteristic of the original Murty plate interferometer, but has the additional advantages of improved accuracy and automated operation.

4. Conclusion

Many different types of liquid crystal spatial light modulators are now becoming available, amongst which are phase-only modulators based on nematic liquid crystals arranged in a parallel configuration. These may be applied in many areas of optics including information processing, and precision measurement. Two measurement applications of this type of modulator have been introduced here—a speckle shearing interferometer for determining rough surface deformation and an automated Murty plate shearing interferometer for the accurate determination of wavefront shape. The ability of this type of modulator, and others such as the Texas Instruments Deformable Mirror Device, to produce arbitrary two-dimensional optical phase modulation distributions under computer control is a new and unique characteristic which gives these devices great potential for the future.

References

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